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We have measured the atomic number (A) dependence of the production cross sections for dihadron states in which each hadron is required to have large transverse momentum. We find that the A dependence varies with the total dihadron transverse momentum in a manner similar to that previously observed for single hadrons.

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For several years the atomic number (A) dependence of hadron production at large transverse momentum ($p_\perp$) has posed intriguing questions.[1-3] The fact that single hadron production cross sections vary as A^α with $\alpha > 1$ implies that the nucleus must act collectively in producing a single hadron at high $p_\perp$. Perhaps the simplest collective mechanism is multiple scattering within the target nucleus.[4-9] More exotic mechanisms include the collective motion of nucleons[10,11] as well as the collective or energetic motion of partons[5,12] - motions which must change as a function of A.

In this experiment we observe two high $p_\perp$ hadrons coming from the same interaction. They are detected in a double arm magnetic spectrometer[13] equipped with Čerenkov particle identification and hadron calorimeter background rejection. We study collisions of 400 GeV/c protons with tungsten (W) and beryllium (Be) nuclei and observe interactions which produce two hadrons emitted back to back at $\sim 90^\circ$ in the proton-nucleon center of momentum. If $p_{\perp +}$ denotes the magnitude of the transverse momentum of the positive member of a hadron pair of net charge zero, it is convenient to define the following two quantities:

$$m' \equiv p_{\perp +} + p_{\perp -}$$

$$p_{\perp N} \equiv p_{\perp +} - p_{\perp -}$$

For a pair with small $|p_{\perp N}|$, m' closely approximates the mass of the dihadron system. Since our azimuthal acceptance for each hadron is very small ($\sim$0.1 radian), $p_{\perp N}$ approximately equals the net transverse momentum of the pair. Then, in order to facilitate comparison to single hadron measurements, we note that dihadron $p_\perp = |p_{\perp N}|$.

The data presented here were obtained using several redundant triggers. The high mass (HM) trigger[13] required m' greater than a preset threshold. Alternative calorimeter pair trigger requirements were formed from the coincidence of single-arm requirements triggered by single hadron $p_\perp$ or by single hadron total energy. If T_1 denotes a track (coincidence of three scintillation counters) in arm 1, then the pair trigger consisted of $(T_1 \cdot T_2)$ in coincidence with HM or one of the alternative pair requirements.

In analogy with the case of single hadrons we assume that the dihadron invariant production cross sections for protons incident on a nucleus of atomic number A are proportional to A^α. We then measure α_{pair} using Be and W targets. The luminosity was monitored by a four-counter telescope (N) placed in the neutral beam of one of the spectrometer arms. The target-in/target-out ratio for this monitor was typically 50/1. The N rate was linear versus incident beam intensity as measured by a secondary emission monitor (SEM) up to rates over twice those used during the experiment. Our targets were horizontally narrow (0.22 mm Be and 0.42 mm W) but a large fraction of the incident beam (typically 70% for Be, 95% for W) intercepted the target. The calibration of N/SEM for protons intercepting the target was carried out through the use of horizontal target scans. This calibration repeated within an accuracy of 5% over the course of the experiment and was checked for Be with the use of a wide (2.0 mm) target. Vertically our targets (>6 mm high) were much larger than the beam (which was roughly circular in cross section). The target lengths were 103 mm for Be and 13 mm for W.

If n represents the number of events detected, we define the W/Be yield ratio

$$Y = (n/N)_W/(n/N)_{Be}$$

and calculate α according to the prescription

$$\alpha = \ell n(CY)/\ell n(A_W/A_{Be})$$

where C = 11.7 for our target-monitor system.[14]

Corrections have been made for absorption of incident protons and secondaries in both targets. Approximately 13% of the pair events are lost from these mechanisms with either target.

We have monitored our W/Be relative efficiencies from the repeatability of our single hadron yields as well as from direct efficiency measurements. Stability of the data triggers was monitored throughout our A dependence measurements by the use of special runs with less restrictive triggers. The efficiencies of proportional wire chambers (PWC) and scintillation counters not required in the trigger were monitored during data taking. Corrections for small efficiency changes ($\sim$10% in Y) have been made to the data. We estimate our total single arm systematic uncertainty to be $\pm.03$ in α, arising from uncertainties in both relative normalization and relative efficiency.

Since we wish to study correlated hadron pairs, arm to arm accidental coincidences (originating from two separate but simultaneous interactions in the target) were subtracted from the pair yields. The coincidence rate ($T_1 \cdot T_2$) was observed to vary as the square of the incident beam intensity (±10%) and was used to normalize spectra of uncorrelated pairs generated by combining spectra of single arm triggers (recorded simulteneously with the pairs). The resulting fraction of accidental pairs amounted typically to 40% of the total for W and 20% for Be for a 1 GeV/c bin in m' just above threshold. The fraction of events subtracted decreases rapidly as m' increases (factor of 2 decrease for 1 GeV/c increase in m') but does not vary strongly with dihadron $p_\perp$. Data were taken with thresholds ranging from m' = 4.5 to m' = 6.5 GeV/c with corresponding adjustments of the beam intensity over a factor of 5. All data samples and all triggers yield consistent results. In addition the subtraction has been checked for m' well below threshold where essentially all of the pairs are accidental. Consequently we believe that we can perform the subtraction of accidental pairs to an accuracy of 20% of itself.

We estimate our total systematic uncertainty from all the above effects be ±.06 in α for pairs. In the data that follow, the quoted errors are purely statistical since point to point comparisons are largely free of the systematic uncertainties.

In Fig. 1 we show α values for dihadrons (without regard to particle identification) as a function of $p_{\perp+}$ and $p_{\perp-}$. For single hadron $p_\perp$ values less than 1 GeV/c we do not accept hadrons into our apparatus, so we use the corresponding locations in Fig. 1 to display our single hadron α values measured simultaneously with the pair values. Near the center of the plot the pair α values are low. In particular, if we require a positive hadron with $p_{\perp+}$ between 3 and 4 GeV/c in addition to a negative hadron between the same $p_\perp$ limits, α

drops by 0.22 ± 0.07 relative to the value for the negative hadron alone. (Here we include a systematic uncertainty of 0.05 for the random pair subtraction.) This change in α corresponds to a factor of two drop in Y relative to what one would expect if pair and single arm α values were equal.

In Fig. 2 we rebin the data from Fig. 1 and examine the dependence of α on m' and dihadron $p_\perp$. If we integrate over all $p_{\perp N}$, α is flat versus m' and consistent with 1. We note, however, that α rises significantly above 1 for dihadron $p_\perp$ values greater than 2 GeV/c. This is especially evident for high m' where large $p_\perp$ values are accessible. We compare the results to our single hadron α values and to previously measured[15] single hadron values also plotted versus $p_\perp$. The hadron and dihadron A dependences show similar increases in α at high $p_\perp$. Thus it appears that the transverse momentum delivered to the final state determines the A dependence of the production of that state for states of two hadrons emerging back to back in the center of momentum after a hard collision as well as for single particle states.

In Fig. 3 we show the variation of α with the species of the final state. Since α does not vary strongly as a function of m' we integrate over all m' above threshold and display separately α for $p_\perp$ less than and greater than 2.1 GeV/c. Unfortunately because our pair identification efficiency is concentrated near dihadron $p_\perp = 0$, we cannot make definite statements regarding the species dependence of the rise in α_{pair} versus $p_\perp$. We can, however, see significant species dependence of α at low dihadron $p_\perp$. The values of α are especially high for pK^- and $p\bar{p}$ states, which contain two particles, each with a single hadron α value which reaches 1.3 at high $p_\perp$.

In conclusion, we find that the dihadron A dependence in the hard-scattering region exhibits a behavior as a function of $p_\perp$ similar to that observed for single hadrons. But, integrating over all $p_\perp$, the average α_{pair} is consistent with 1 for $m' > 4.5$ GeV/c. As was evident from single hadron results,[1] the quantum numbers of the state produced play an important role.

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[14]If $k \equiv (N/SEM) \times (A/(\text{Avogadro's number} \times \text{density of target} \times \text{length of target}))$ then $C = k_W/k_{Be}$.

[15]We calculate α for hadrons (averaged over charge) using α values for π, K, p from Ref. 1 and particle ratios from J. W. Cronin et al., Phys. Rev. D11, 3105 (1975).

$P_{\perp -}$ (GeV/c)	SINGLE ↑	1–2	2–3	3–4	4–5	5–6	6–7
5–6	1.14 ±0.21	1.34 ±0.23	1.20 ±0.13	0.52 ±0.41	1.41 ±0.27		
4–5	1.16 ±0.05	1.08 ±0.11	1.04 ±0.07	1.11 ±0.09	1.17 ±0.17		
3–4	1.11 ±0.01	1.14 ±0.07	0.98 ±0.05	0.89 ±0.05	0.90 ±0.10	1.12 ±0.17	
2–3	1.03 ±0.01		1.01 ±0.04	1.00 ±0.05	0.95 ±0.08	1.16 ±0.12	1.65 ±0.33
1–2	0.97 ±0.01			1.01 ±0.08	1.07 ±0.11	1.50 ±0.20	0.81 ±0.68
SINGLE →		0.97 ±0.01	1.06 ±0.01	1.12 ±0.01	1.09 ±0.03	0.94 ±0.16	1.33 ±0.47

$P_{\perp +}$ (GeV/c)

Fig. 1. The powers α of the A dependence of the invariant cross sections for production of dihadrons and single hadrons are given as a function of $p_{\perp +}$ and $p_{\perp -}$.

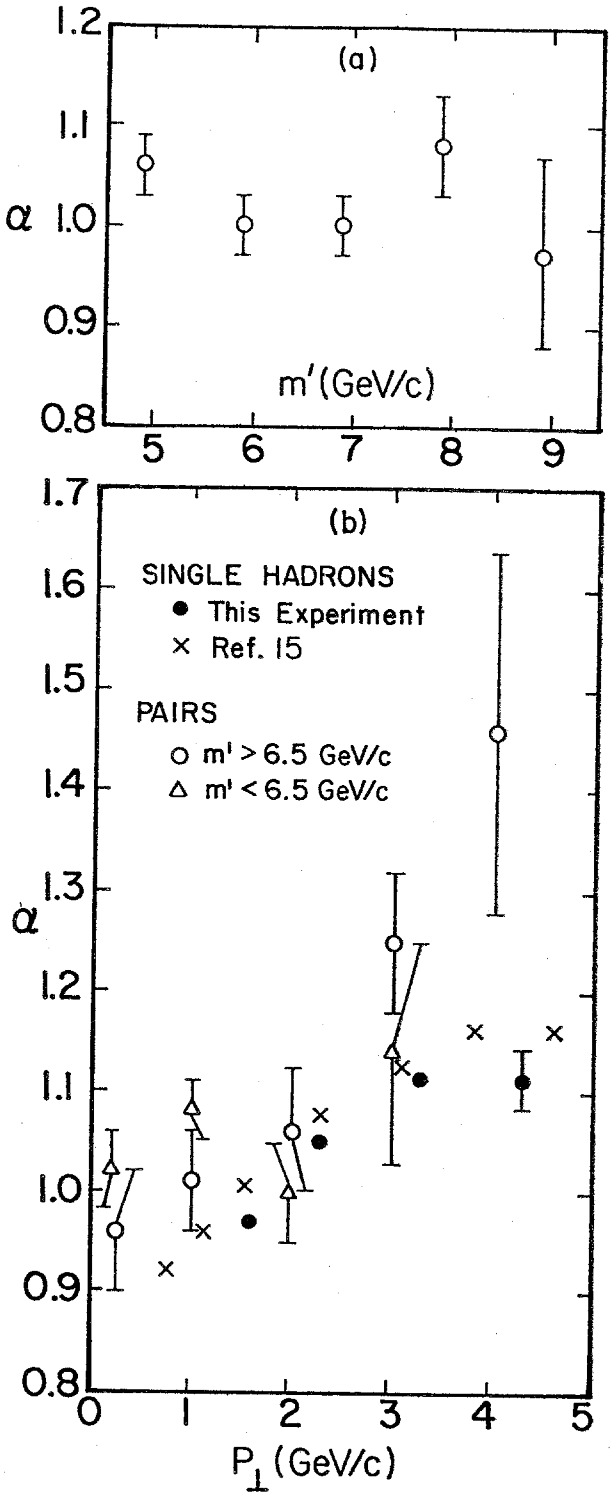

Fig. 2. The power α of the A dependence of the invariant dihadron production cross section is plotted (a) as a function of m' for all $p_\perp$ and (b) as a function of $p_\perp$ for m' < 6.5 GeV/c and for m' > 6.5 GeV/c. Comparison is made to the single hadron A dependence. Statistical errors are shown when they are larger than the points.

	π^-	K^-	$\bar{P}$	h^-
π^+	0.99±0.03 1.08±0.11	1.05±0.09 1.37±0.46	1.29±0.14 —	1.00±0.03 1.12±0.08
K^+	0.98±0.09 —	1.33±0.17 —	— —	1.05±0.06 1.24±0.22
P	1.11±0.07 —	1.58±0.21 —	1.37±0.13 —	1.16±0.05 1.14±0.19
h^+	1.00±0.02 1.15±0.06	1.11±0.06 1.52±0.20	1.17±0.07 1.41±0.43	1.01±0.02 1.18±0.04

Fig. 3. The power α of the A dependence of the invariant dihadron production cross section is given as a function of particle species for $p_\perp < 2.1$ GeV/c (upper value) and for $p_\perp > 2.1$ GeV/c (lower value in each box). h^+ denotes all positive hadrons.